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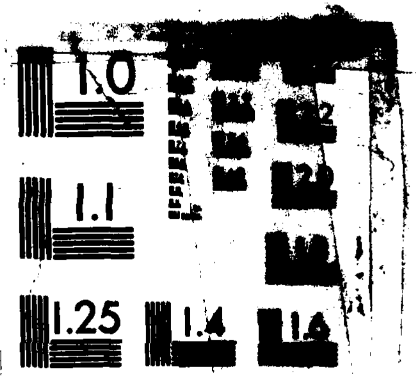

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AFGL-TR-85-0054

INVESTIGATION OF MAGNETIC FIELD MEASUREMENTS

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS

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"This technical report has been reviewed and is approved for publication"

DAVID J. KNECHT
Contract Manager

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Weston Observatory of Boston College has cooperated with AFGL personnel in the maintenance of the Air Force Geomagnetic Network. The computer facilities for processing the data of the Network were upgraded. Fluxgate data for every month of the period 1978-1983 has been depositied in World Data Center A. Daily magnetograms have been produced and will be published by AFGL. Some preliminary processing data to establish substation conductivity was initiated. The Network was discontinued in December 1983.

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1.0 Introduction

The subject contract is the final one in a series which dates back to 1969. At that time, Weston Observatory (Boston College) under contract F19628-68-C-0094, was packaging for AFGL, instrumentation flown on ionospheric/magnetospheric sounding rockets. When the Air Force (AFGL) decided to curtail the ionospheric experiments and to install a network of magnetometers, Weston Observatoy, because of its experience in constructing a magnetic observatory, was asked to submit a design of and specifications for the housing of the magnetometers and all associated electronics. The report was accepted and Weston Observatory continued through a series of contracts (1) to cooperate with Air Force personnel in the installation and maintenace of the Air Force Magnetometer Network and in the processing of the data produced by the Network.

The Network has been described by Knecht et al. (2). Figures 1a and 1b show the locations of the seven stations of the Network. Figure 2 illustrates a typical geomagentic station of the Network.

Procurement of the trailers and accessory equipment began in the Spring of 1973. Prior to that time the Air Force had initiated the purchase of the fluxgate magnetometers (from UCLA) and the induction coil magnetometers (from Geotronics Corp.). As the equipment was delivered to Weston, it was tested, installed in the trailers, and shipped to the sites. The dates of installation are shown in Table 1. The installation process was slow. There were uncertainties in funding since all contracts had the "subject to limitation of funds" clause. There were many delays in delivery of equipment; the distances involved were large. In contract reports (1) the hazards (rattlesnakes), problems (lightning) and modifications of the equipment are cited in detail. In July 1983, the Air Force decided that the network would cease to operate on December 30, 1983. The contract continued until September 1984 with the sole objectives of processing the accumulated data and of dismantling the stations.

Table 1

SITE	DATE OF INSTALLATION
Michigan	November 1974
Newport	December 1974
Wisconsin	January 1975
South Dakota	August 1975
Sudbury	August 1975
Florida	June 1976
California	November 1977

2.0 Specific Tasks of the Contract

2.1 "Develop a reconfiguration of the data acquisition station to replace obselete equipment thus allowing the use of more advanced analysis methods and the use of equipment which had not yet been interfaced."

The digital data from each station of the Network were transmitted to AFGL, Bedford, on a dedicated Western-Union circuit, received and decoded by a minicomputer and stored on magnetic tape by a dedicated minicomputer. The archived data then were processed on the same minicomputer, the Varian V72, with the VORTEX I operating system and 32k memory. The operating system of this computer had been so modified and was so old that it was no longer serviced by the manufacturer and had proved to be too small for the tasks required in reducing the data to acceptable magnetograms and cleaned, edited and reformatted user tapes. In the Spring of 1982, the decision was made to update the minicomputer facilities. After much planning and consideration of many different computer configurations, it was decided to purchase a V77-810, with VORTEX II G.1 operating system and 128K memory from Sperry-Univac,(successor to Varian) primarily because the existing software was built for the Univac system and much peripheral equipment had been adapted to the Univac system. The planned configuration of the computer system is shown in Figure 3.

Purchase of the minicomputer and associated units was initiated in September 1982. The units were delivered in March 1983. The system was fully operative in July 1983. The production of magnetograms and data tapes will be described in a later section.

2.2 "Develop improvements in the instrumentation of the remote network of stations to upgrade the performance and reduce the vulnerability to malfunction."

In the event of a malfunction of components at a station, the normal procedure was for Weston personnel to join AFGL personnel in a visit to the site. If the failure could be repaired on site, it was done. If the malfunction was severe, the equipment was returned to Weston for repair. To reduce the amount of travel and to speed the return to operation of the stations, Dr. Knecht of AFGL arranged for the assistance of Air Force personnel at each site. The designated individual was notified by phone of the problem. Then repairs were made under telephoned directions from Weston. Each station had a supply of 'most likely to fail' components and very detailed drawings of the electronic circuits. In the term of this contract, the Florida station was refurbished. There was serious damage done to the searchcoil electronics at Wisconsin by lightning; the repairs were made.

Plans were made to build a replacement for the electronics of the searchcoil magnetometer using state-of-the-art techniques in linear integrated circuits and modular assembly. Additional protection against lightning was planned. Lack of funds and the prospect of early termination of the Network inhibited construction.

A major cost of the operation of the Network was the use of dedicated phone lines. Thought was given to the design of on-site storage of the data and of automated interrrogation and transmission of the data at a time of day when the phone costs would be minimal. But from July to December 1983, there were no further efforts (or funds) to implement the proposal in view of the scheduled shutdowm.

2.3 "Conduct studies for the monitoring and prediction of magnetic disturbances."

AFGL was interested in the prediction of magnetic disturbances which might interfere with communications systems. The data gathered by the Network were used to define those conditions in the external magnetic field of the earth which might be used to predict geomagnetic disturbances. Ground based magnetic recordings provide a measure of the geomagnetic field vector as a function of time. This vector measures a combination of the external magnetic field and the internal magnetic field induced in the conducting earth by the varying external field. Hence a separation of the two fields is necessary to the definition of the external field. In this context it is important to be aware of the earth's geologic structure and its expression in terms of the nonuniform electrical conductivity of its mineralogy. The behavior of a uniform conductor in the presence of a varying magnetic field is relatively easy to predict. The nonuniform character of the earth's conductivity makes the prediction of internal magnetic fields quite difficult. In fact the global average electrical conductivity structure of the earth is not well known. Detailed knowlwdge of crustal and upper mantle electrical conductivity has been defined for only a few areas where extensive magnetic or magnetotelluric surveys have been made.

Because the separation of internal and external magnetic fields is so crucial to an exact definition of the external field, we decided to try to define the conductivity structure beneath and adjacent to the stations of the Network. Knowing the local conductivity structure, we might be able to predict the internal magnetic field induced by specific external fields. Gauss (3) showed that there is a unique solution to the problem of the separation of the internal and external fields. The ratio of the internal to the external field, derived from the ratio of Z/H or Z/D, can be used as a nonunique measure of the earth's electrical conductivity.

From AFGL we acquired the first three months of data for the year 1979. The period of the magnetic variation determines, along with the conductivity, the depth of penetration of the inducing field. The data must be Fourier analyzed to achieve the separation of periods. Because there is a wide range of periods, we separated the period domain into three parts, periods greater than two days, periods associated with the daily variation (24,12,8,6,4 hours) and periods less than two hours. Different methodologies were developed to deal with each period range.

The input to the analysis of the long period variations was the hourly averaged values of H and Z. We should note that due to instrumental failures or phoneline interruptions, there are data gaps lasting variously for minutes, hours or days; we do not have a data set of ninety days. Uninterrupted intervals of data were detrended, zero-meaned, smoothed with a three point phase-distortionless filter, then Fourier analyzed. The components, H(North), D(East), Z(Vertical) of the total field are defined:

$$Z(f) = (nE(f) - (n+1)I(f))\, P_{n,m}(\theta)$$
$$H(f) = (E(f) + I(f))\, P'_{n,m}(\theta)$$
$$D(f) = (E(f) + I(f))\, P_{n,m}(\theta)/\sin(\theta)$$

where P(n,m), P'(n,m) are the Associated Legendre polynomials (funtions of latitude) and their derivatives; E and I are the external and internal fields. Separation of internal and external fields requires knowlwdge of the latitudinal (n) and longitudinal (m) character of the inducing field. Normally, separation of the fields demands data at a large number of latitudes. Since five of the stations are at the same latitude, mode separation by the standard least squares technique is not possible. We simply assumed that the P(1,0) mode, indicative of a ring current, was the prevailing source and attempted separation at each station from the ratio of Z/H. Only after stacking many spectra of 10 days of data could a P(1,0) mode be assumed. Even then the results were far from satisfactory, clearly insufficient to define a conductivity profile for the deep mantle beneath the stations. For long periods (10 days) the penetration depth was 1000-1200 km.; the conductivity was high, 5 mho/m. But the results for all periods are not internally consistent; for example, the depth of penetration for the five day period is nearly the same as that for the ten day period, but the conductivity is much larger. The expectation is that a longer period would penetrate deeper to a zone of higher conductivity.

The analysis of the daily variation is simplified because we know the longitudinal dependence,m, (submultiples of a period of one day) and the latitudes. The hourly mean values of H, D, Z are Fourier analyzed day by day and the ratios Z/H, Z/D are analyzed by the Schmucker methodology (4) to determine the depth of penetration and the conductivity at that depth. Again the results are far from satisfactory. Figure 4 shows the spread of the values in both amplitude and phase of the ratios at the 24 hour period for all useable data (days on which there are no missing values) from all the stations. These unsatisfactory results prompted a review of the data. Figure 5 shows a data interval at the South Dakota station. The obvious transients will generate an erroneous spectrum; all further analysis depends on the spectrum. To continue the analysis, the data, sampled at one minute intervals, will have to be carefully scanned to remove such transients and the hourly values recalculated.

A function, known as the single station transfer function, can be used at higher periods (shorter than two hours) to give a qualitative estimation of the change of conductivity with frequency. The basic notion is that the internal field is made up of a normal part due to uniform conductivity and an anomalous part due to a departure from normal conductivity. This departure will produce an anomalous Z component, generated by a horizontal component in the anomalous conductor. If it is assumed that the normal Z is negligible and does not correlate with the other two horizontal components and that the anomalous parts of the horizontal fields are small, then we write:

$$Z_a = AH + BD + \text{error}.$$

A and B are referred to as the single station transfer functions; all quantities are complex. Finding A and B requires Fourier transformation of data intervals(sampled once a minute) which contain short period variations. Many samples of the transforms at a single period are used to solve the equation by least squares. The error is a measure of how well the assumptions are satisfied. The transfer functions are used to calculate induction arrows (both real and quadrature) which point toward or away from anomalous conductivity structures. Figures 6 and 7 show samples of the real induction arrows for two of the sites. Knowledge of the regional geology will aid in identifying the anomalous conducting structure.

Work on this topic ceased at the end of December 1983 when a modification of the work statement became effective. We have learned, with respect to the long period data: (1) that significant results demand very careful scanning of the minute-average component values to remove all transients, and (2) that because the D component has significant power at long periods, the assumption of a P(1,0) source is not always valid. At 55 degrees North magnetic latitude, the auroral zone return currents contribute a considerable E-W magnetic field which is incompatible with the assumption of the P(1,0) source. With regard to the daily variation, it may be better examined through complex demodulation. This is a method of averaging intervals of continuous days of data and gives, in the time domain, a measure of the variability and phase of the components of the daily variation. As well, the day by day spectra should be separated into classes, based on the rms of the variations because the external field is different for quiet and disturbed days. Figures 6 and 7 show relatively consistent vectors indicating conductivity anomalies. There is suspicion that we have analyzed only variations which are due to the dominant polarization of the source field. A search must be made in the daily magnetograms for a variety of polarizations

2.4 In the final phase of the contract there were two tasks: (1) assist AFGL in the disassembly of the stations and (2) process the archived data of the Network.

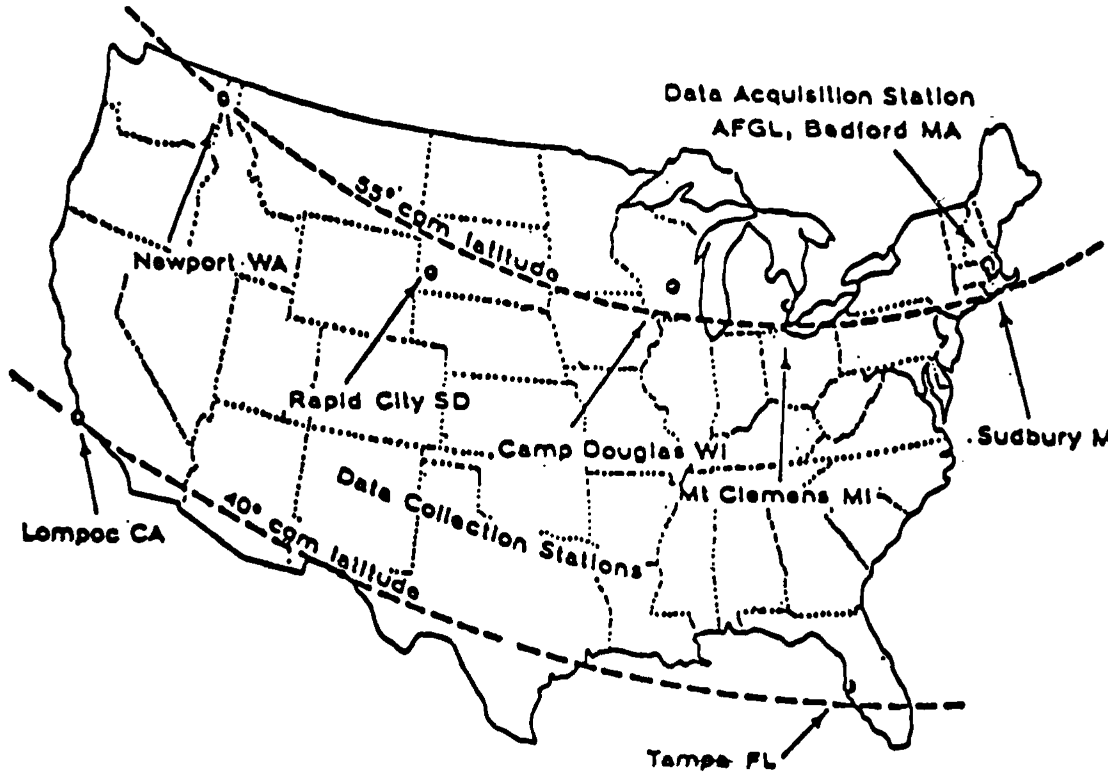
Several research organizations petitioned the Air Force to acquire the equipment of the Network. When the disposition of the equipment is final, the organizations will aid in the removal of the equipment from the sites.

Our research assistant, Armand Paboojian, has authored a Technical Report(5) which describes in detail the editing of the archived tapes on which the raw data from the seven Network stations were recorded. The structure and data content of the archived tapes have been described by Knecht (6). The edited tapes have either a one-second or a one-minute (averaged) sampling interval and are written in a tape format compatible with computers used at AFGL and World Data Center-A. Detailed instructions are given for each of the computer programs used in the process as well as for the basic operation of the Network minicomputer. The procedure is highly automated and the description is sufficient to permit its being carried out by an untrained operator. The data processing, for the most part, was carried out by our student (both high school and college) assistants who quickly became very skillful computer operators.

It must be emphasized that we have processed only the fluxgate magnetometer data. The data from the induction coil magnetometers have not been processed. Tapes of the fluxgate magnetometer data for every month of the period 1978-1983 have been deposited in the World Data Center-A, Boulder Colorado. Daily magnetograms for each station are to be published by the Air Force. In this way the magnetic variation data of the Network are available to the scientific community.

3.0 Conclusion

The Air Force Magnetometer Network, in its entirety, operated for more than six years. In the later stages of its existence the minicomputer facilities for the processing of the data were expanded. After recording ceased on December 30, 1983, all the fluxgate data were processed and sent to World Data Center-A from where it is available to interested researchers. Initial attempts to define the electrical conductivity of the earth in the vicinity of the stations were quite inconclusive but have clearly defined the problems and have produced protocols for further investigation.

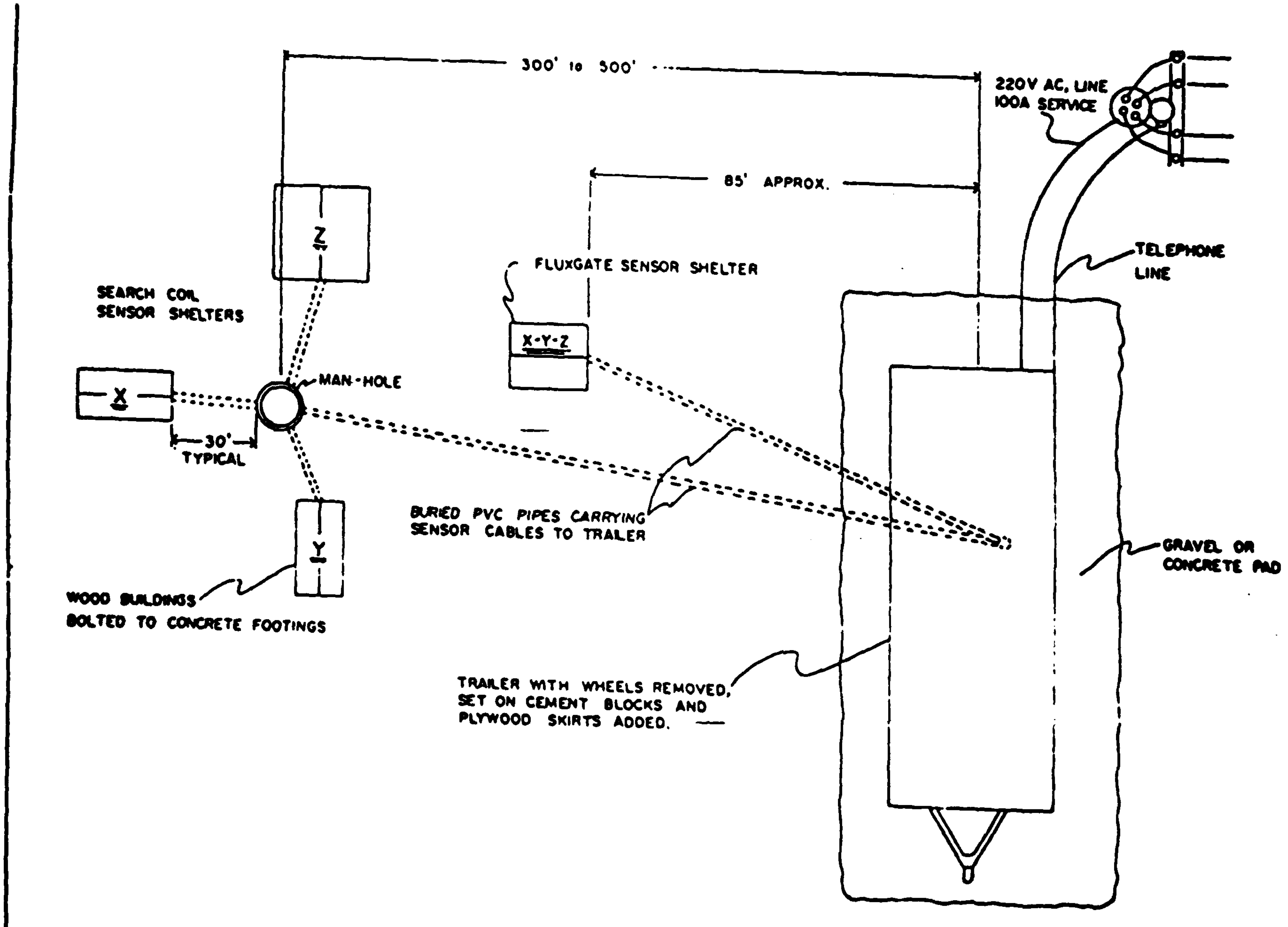


Geographic Locations of the Network Stations

Figure 1a

STATION NAME	Corrected Geomagnetic Coordinates		Geographic Coordinates		
(Post Office)	N Lat	E Long	N Lat	E Long	Government Installation
Newport, WA	55.2	299.6	48.3	117.7	USGS Geophysical Obs.
Rapid City, SD	54.1	317.3	44.2	103.1	Ellsworth AFB
Camp Douglas, WI	56.3	334.2	44.0	90.3	Volk Field
Mt. Clemems, MI	55.8	344.8	42.6	82.9	Selfridge ANG Base
Sudbury, MA	55.8	1.9	42.2	71.3	Army Natick Lab. Annex
Lompoc, CA	40.2	300.6	34.7	120.6	Vandenberg AFB
Tampa, FL	40.7	344.9	27.8	82.5	McDill AFB

Figure 1b



TYPICAL REMOTE GEOMAGNETIC OBSERVATORY LAYOUT

Fifure 2

REVISED CONFIGURATION
30 August 1982

Code	Source of Equipment
N	New from Univac
A	Available from customer on V77 delivery date
D	Delayed; from customer at final changeover
F	Future; not scheduled

```
| V77-810    N|---| OPCOM CRT            N|
| FPP         |
| WCS         |---| POWER SUPPLIES       N|
| 256 KB      |
  |
  |------|---| LOCUST DISC                        N|---| LOCUST DISC           N|
  |      |   | INCLUDES BIC #1                     |
  |      |
  |      |---| PIM #2                             N|
  |
  |------|
  | | I/O EXPANDER #1     N|
  |     |
  |     |---| MAG TAPE 9-TRACK                    N|---| MASTER UNIT           N|
  |     |   | INCLUDES BIC #2                      |   | SLAVE UNIT            N|
  |     |
  |     |---| BIOC #1  (FOR DDU)                  A|---| DATA DECODER UNIT     A|
  |     |---| BIC #3                              N|
  |     |
  |     |---| VERSATEC CONTROLLER                 A|---| VERSATEC PLOTTER      A|
  |     |---| BIC #4                              N|
  |     |
  |     |---| UASC (DEKPRINTER)                   N|---| DEKPRINTER            A|
  |     |---| BIC #5                              N|
  |     |---| STATOS                              A|---| STATOS PLOTTER        A|
  |     |
  |     |---| BIOC #3  (FOR MUX)                  N|---| MULTIPLEXER           F|
  |     |
  |     |---| PIM #1                              N|
  |     |
  |     |---| PIM #3                              N|
  |    TS
  |
  |------|
  | I/O EXPANDER #2     D|
     |
     |---| MAG TAPE 7-TRACK                    D|---| MASTER UNIT           D|
     |---| BIC #6                              N|   | SLAVE UNIT            D|
     |                                             | SLAVE UNIT            D|
     |
     |---| DIABLO DISC                         D|---| DIABLO DISC UNIT      D|
     |---| BIC #7                              N|
     |
     |---| BIOC #2  (FOR BKP)                  D|---| BACKUP SYSTEM         F|
     |---| BIC #8                              N|
     |
     |---| BIOC #4  (FOR AWS)                  A|---| AWS SYSTEM            F|
     |
     |---| UASC (FOR TEKTRONIX)                D|---| TEKTRONIX 4014        D|
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    TS
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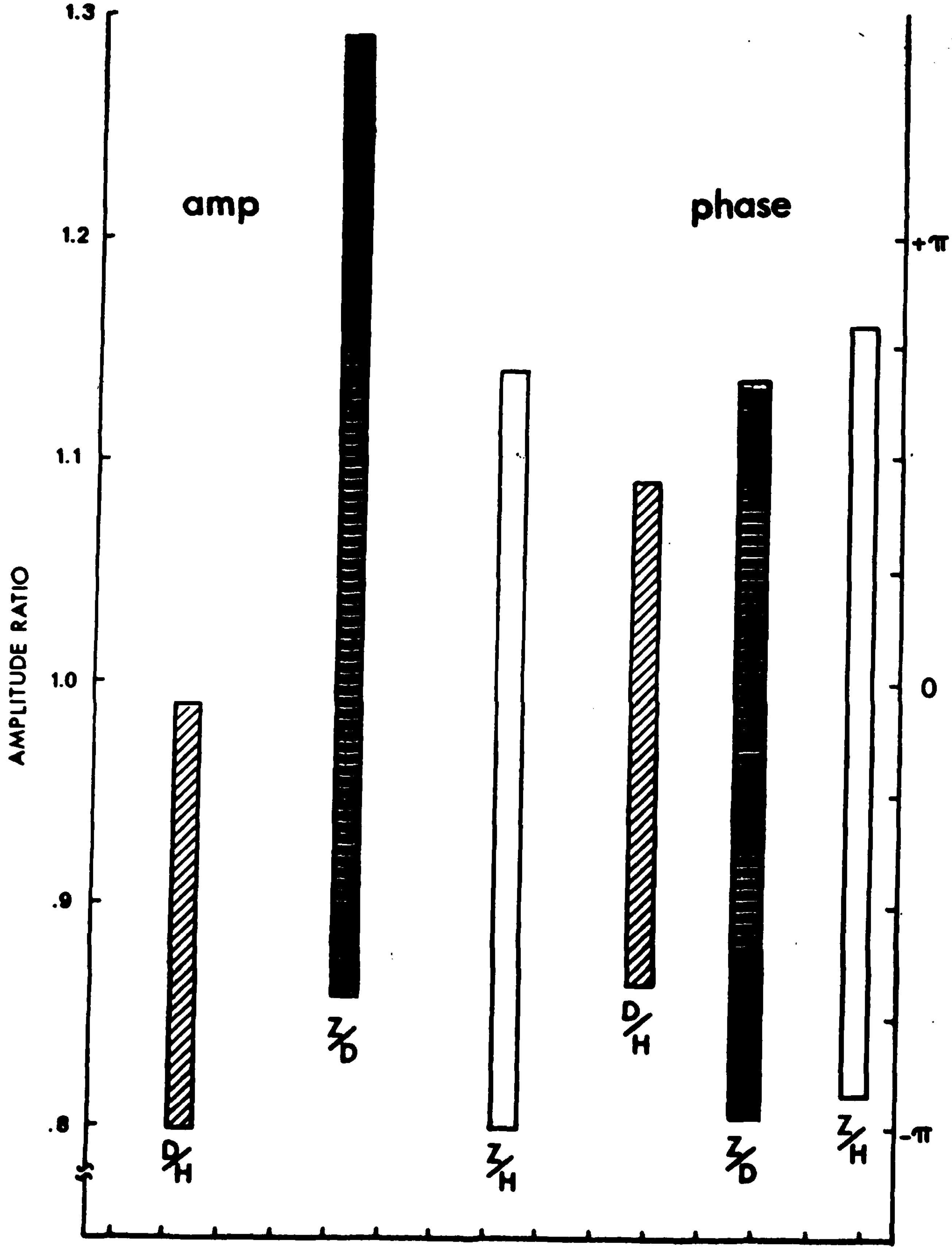

Figure 4

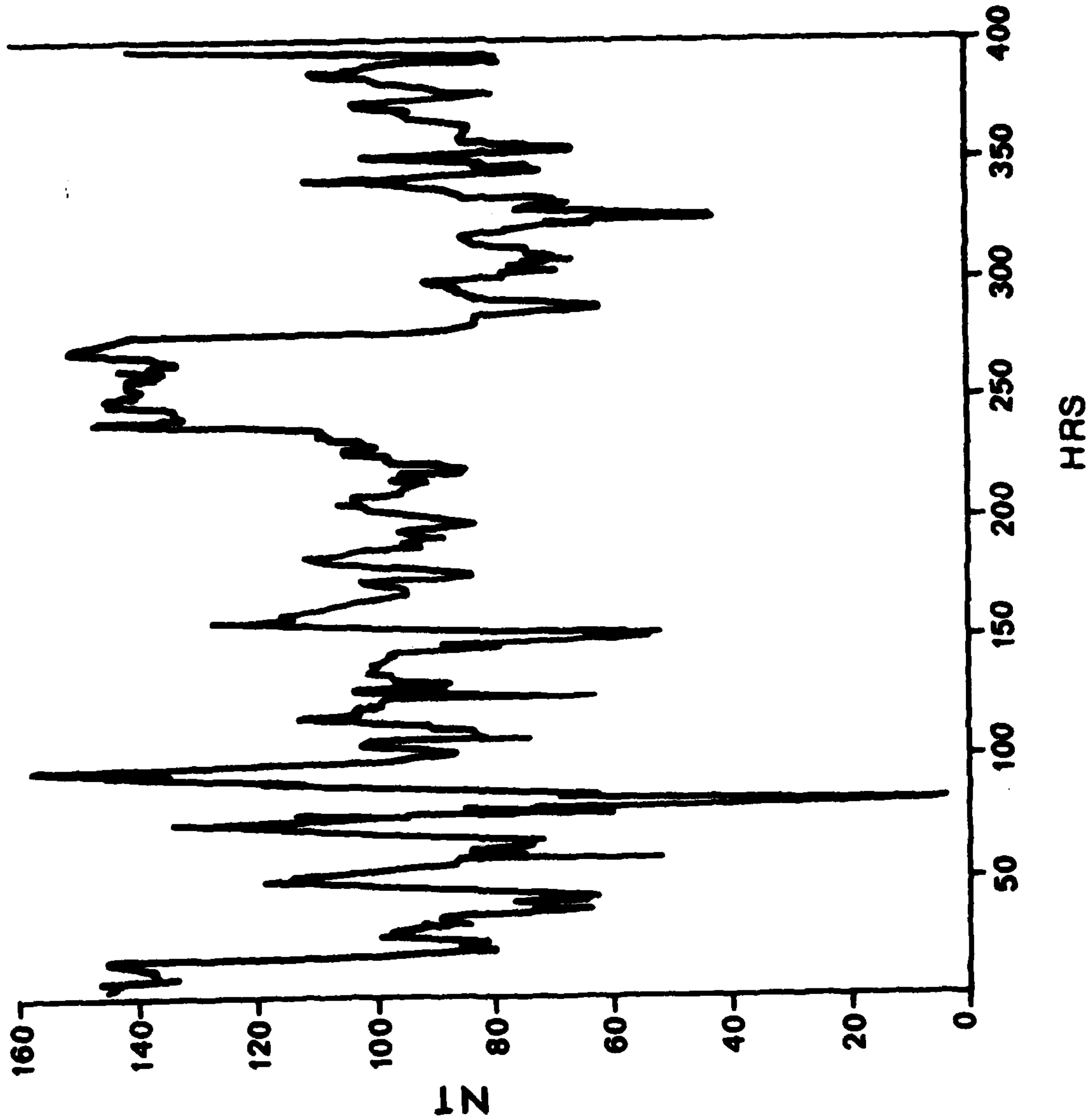

Figure 5

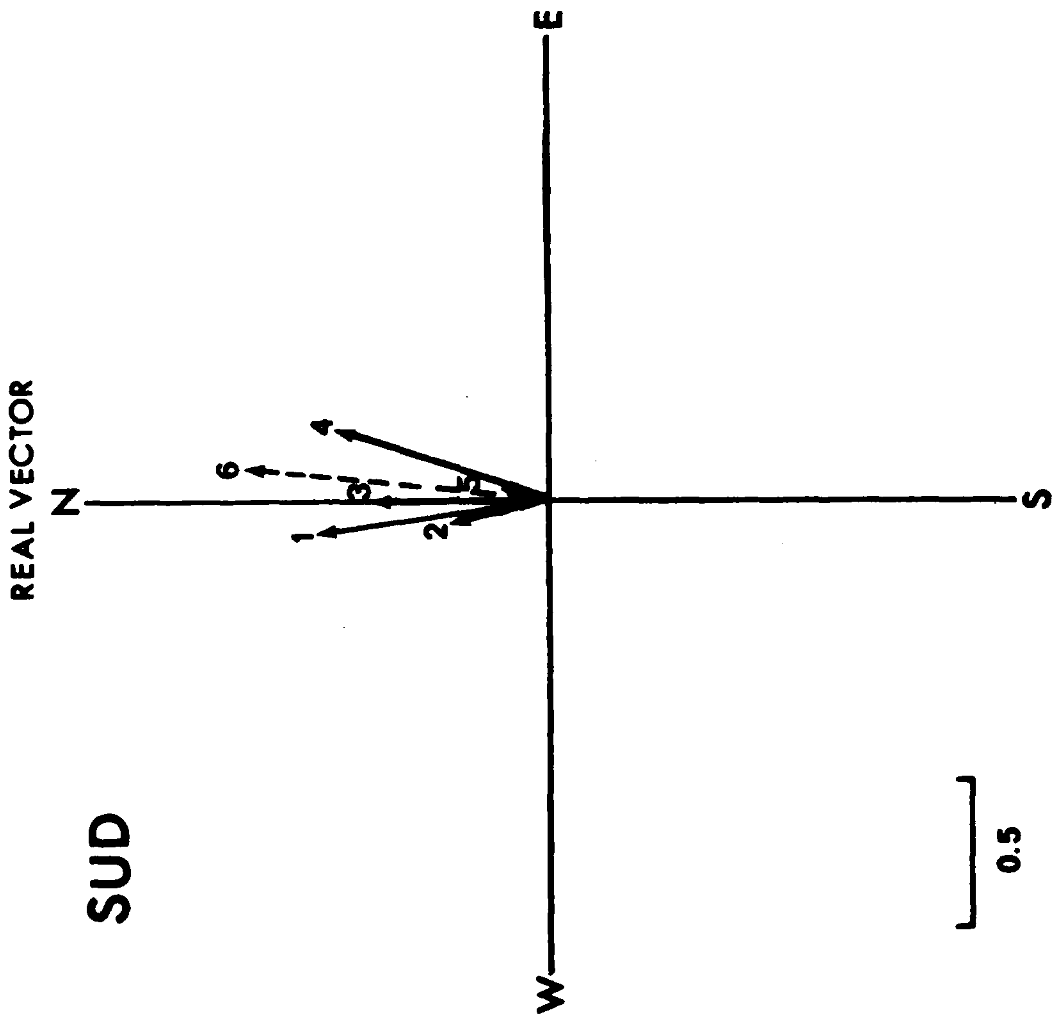

Figure 6. Length of induction arrows normalized to maximum.
1-60 minute period, ... 6-10 minute period.

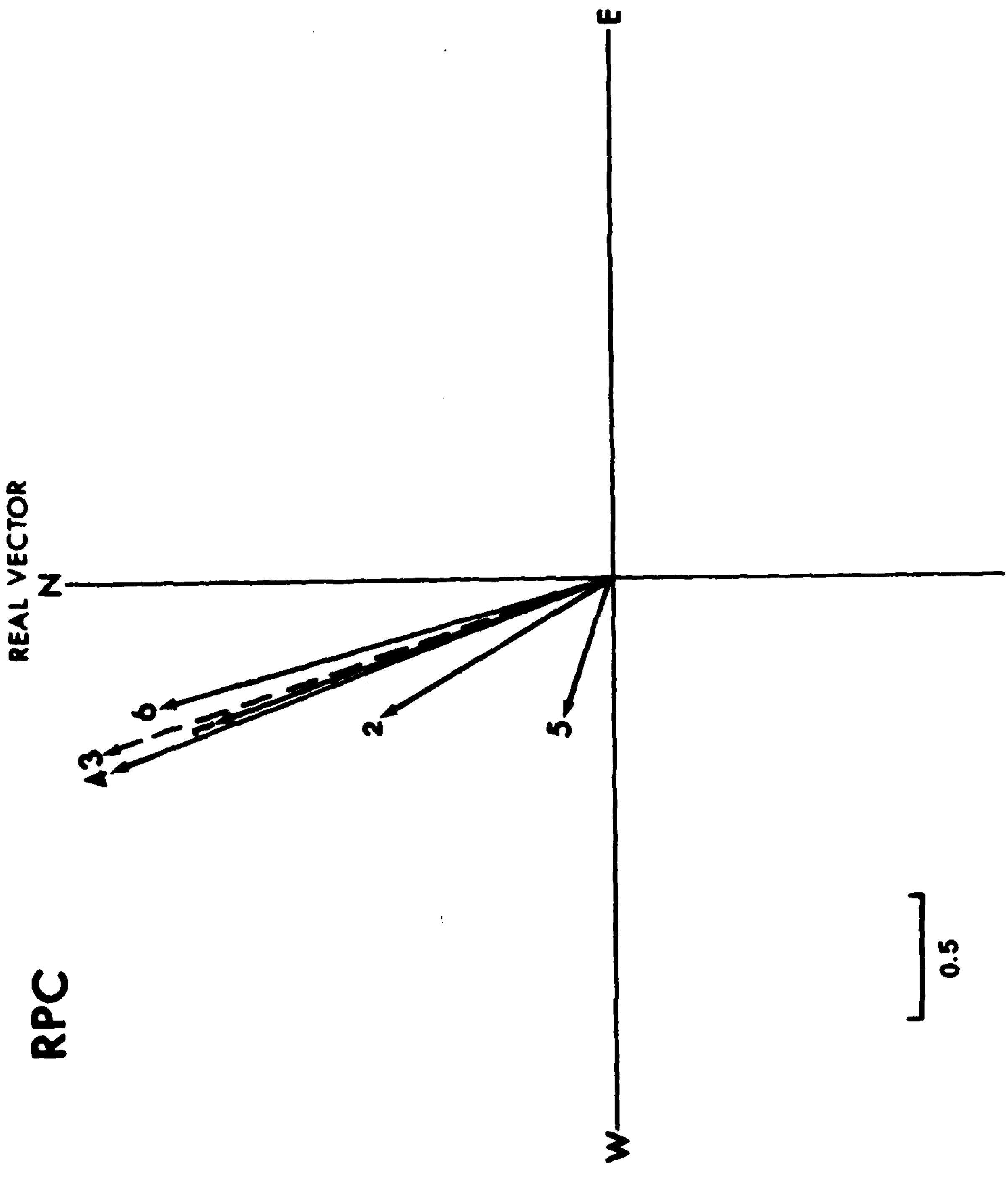

Figure 7. Lengths of induction arrows.
Cf. Fig. 6.

REFERENCES

1. Devane, S.J., J. F., Investigation of Magnetic Field Measurements, Final Report of Contract F19628-80-C-0005, Hanscom AFB, MA., AFGL-TR-83-0058, 1983, ADA130422.

Devane, S.J., J. F., Investigation of Magnetic Field Phenomena in the the Ionosphere, Final Report of Contract F19628-C-76-0291, Hanscom AFB, MA., AFGL-TR-80-0099, 1980, ADA087526.

Devane, S.J., J. F., E. A. Johnson and R. Dalrymple, Investigation of Magnetic Field Measurements in the Ionosphere, Final Report of Contract F19628-C-74-0003, Hanscom AFB, MA., AFGL-TR-76-0230, 1976, ADA037541.

2. Knecht, D. J., R.O. Hutchinson and C. W. Tsacoyeanes, An Introduction to the AFGL Magnetometer Network, Hancsom AFB, MA. AFGL-TR-79-0108, 1979, ADA068879.

3. Gauss, C. F., Allgemeine Theories des Erdmagnetismus, Gottingen, 1838.

4. Schmucker, U., Anomalies of Geomagnetic Variation in the Southwestern United States, Bull 13, Scripps Inst. of Oceanography, LaJolla, CA., 1970.

5. Paboojian, A. J., Procedure for Editing Magnetometer Data of the AFGL Magnetometer Network, Scientific Report No.1 of Contract F19628-82-K-0040, Hanscom AFB, MA., AFGL-TR-84-0275, 1984. (In press)

6. Knecht, D. J., Archive Data Tapes of the AFGL Magnetometer Network, Hanscom AFB, MA., AFGL-TR-79-0212, 1979, ADA084483.

PREVIOUS CONTRACTS

AF 19604 3504	Apr. 1, 1957 - Mar. 31, 1959
AF 19604 5569	Apr. 1, 1959 - Sept. 30, 1961
AF 19628 236	Oct. 1, 1961 - Oct. 31, 1964
AF 19628 4793	Nov. 1, 1964 - Oct. 31, 1967
F19628-69-C-0094	Nov. 1, 1967 - Oct. 31, 1970
F19628-69-C-0100	Nov. 1, 1967 - Oct. 31, 1970
F19628-71-C-0083	Nov. 1, 1970 - Oct. 31, 1973
F19628-74-C-0003	Aug. 1, 1973 - June 30, 1976
F19628-76-C-0291	July 1, 1976 - Sept. 30, 1979
F19628-80-C-0005	Oct. 1, 1979 - Sept. 30, 1982

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